

**REMARKS**

The subject invention relates to an optically pumped semiconductor (OPS) laser. As recited for example in claim 1, the OPS laser includes a multilayer structure wherein a mirror is surmounted by a gain medium. A heat conducting member is connected to the multilayer structure. In the prior art, this connection was made via adhesive. In the subject invention, the connection is made without adhesive. Instead, the connection is created via a pressure contact bond which remains "fixed without adhesive after the pressure has been removed."

In a series of Office Actions, the Examiner has repeatedly rejected the claims based on prior art **which does not teach this invention**. More specifically, the Examiner relies on the commonly owned Salokatve patent (6,327,293) and Brewley patent (6,448,642). Salokatve discloses the admitted prior art of an OPS laser wherein the gain medium is adhesively connected to the heat conducting member. Brewley teaches a gain medium and heat sink which are held in place with a screw. In other words, Brewley fails to teach an assembly which will remain fixed after the pressure has been removed. (Bewley at column 9, line 41 states that the "bond is in no way permanent. When the pressure is removed, the materials separate, without any damage to either surface.")

Applicants have previously amended the claims to make the distinction over the prior art clear. Applicants have pointed to various sections in the specification which describe the bond. For example, at page 5, line 2, the specification states:

Chip 16 including OPS-structure 15 is **contact bonded** to surface 18A of the diamond heat spreader, here, with Bragg mirror structure 14 in contact with the heat spreader as depicted in FIG 1D. **The term "contact bonded", in this description and the appended claims, means that a bond is formed without a physical adhesive between the bonded members. Such a bond is comparable to an "optical contact" that is sometimes used in the optical industry to form an adhesive-free bond between smooth, flat components of optically transparent, solid materials such as glass or fused silica.** Once the contact bond has been formed, it is preferable, albeit not necessary, to heat or anneal the bonded assembly at a temperature between about 100°C and 350°C.

In the Final Office Action, the Examiner noted that specification itself does not provide a detailed description of an optical contact bond. At page 13, the Examiner requested that the Applicant explain what is known in the art as an optical contact bond.

In response, Applicants have attached hereto as Exhibits A and B copies of prior art documents which further explain optical contact bonding.

Exhibit A is an article by Smartt and Ramsay from 1964 which discusses some of the principals of optical contact bonding used to create an adhesive free connection between two glass elements. As stated in the abstract of the article, "These bonds...are permanent under normal conditions but may be dismantled if necessary." The last paragraph of the article describes the difficulty of separating the optical elements once they have been contact bonded. For example, to break the connection, the parts might have to be heated, soaked in a solvent or forced apart with a razor blade.

Exhibit B is U.S. Patent No. 5,724,185 to Hickey. Hickey also states at column 1, line 18 that: "Optical contacting is a well-known and preferred method for joining the elements, because it provides strong contact forces, without introducing the absorption and scatter of conventional adhesives."

At column 1, line 35, Hickey describes the nature of the optical contact bond:

Optical contacting is a process which is **well known to those skilled in the field of optics**. There are varied theories for the mechanism of optical contacting. In one theory, the surfaces are **held together** by the surface tension of a very thin layer of water (or other liquid) located between the two surfaces. In another theory, **mechanical seizure** between the two surfaces occurs because two surfaces in close proximity tend to share a weak contact force (which has been described as the result of sharing electrons, or of sharing electromagnetic fields, or of Van der Waals forces, or of London dispersive forces). When the region of contact has sufficient surface area, a strong contact force is obtained by the cumulative effect of this weak interaction. It has been postulated that in practice, under conditions of greater than 50% relative humidity, a combination of both the surface tension and contact force theories apply. The region of contact between the surfaces must be substantially devoid of impurities, for example dust particles and water stains, to provide for the strongest bond. An absence, or near absence, of air is also necessary to eliminate or greatly reduce optical reflections at the contacted surfaces.

Applicants recognized that this well known technique used for bonding optical components such as glass plates, could be also be used to create a bond between a semiconductor substrate and a heat conducting member. Applicants' specification defines the bond as a comparable to the optical contact bond used in the optics industry. The method is essentially the same. As Applicants noted in the specification at page 10, line 13:

It is preferable when optically contacting a diamond (CVD, natural or type IIa-synthetic) or any other highly thermally conductive heat spreader material to a semiconductor epitaxial layer structure, that the surfaces of both the layer structure and the heat spreader be very clean and very flat, preferably flatter than 0.2 waves at 635 nm. **Standard optical contacting methods are used, well known in the industry.** Regarding cleanliness, it is preferable that contacting be carried out on a class 100 clean bench and that surfaces be finally cleaned with an organic solvent such as acetone, methanol and iso-propanol. Once the heat spreader and the semiconductor chip are clean, one edge of the semiconductor chip is pressed against the heat spreader and the two surfaces are brought into contact with pressure. This usually requires multiple attempts of recleaning and contacting. Once a full surface optical contact has been made, the contacted, assembled structure is annealed at temperatures between 100°C and 350°C. Then the substrate supporting the semiconductor epitaxial layer structure is etched away, leaving the finished optical semiconductor device optically contacted to the heat spreader material.

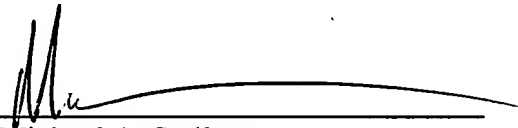
It is respectfully submitted that the documents submitted herewith address the Examiner's concern about what is well known in the industry. Moreover, a comparison of the descriptions of optical contact bonding found in the prior art documents with the description in Applicants' specification shows an almost identical overlap. Accordingly, it is respectfully submitted that the teachings in the specification are more than adequate to provide support of the proposed claim amendments.

It is respectfully submitted that it is patentable to apply the technology known for bonding optical elements such as glass plates to improve the performance of an OPS laser. The prior art relied upon by the Examiner fails to teach the claimed invention. Accordingly, it is respectfully submitted that the pending claims define patentable subject and allowance thereof is respectfully requested.

Respectfully submitted,

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Dated: April 28, 2008

By:   
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Attachments: Exhibit A: - R.N. Smartt and J.V. Ramsay, "On the production and use of the Optical contact bond," *J. Sci. Instrum.* (1964), Vol. 41, page 514.  
Exhibit B: - U.S. Patent No. 5,742,185, issued March 3, 1998, by Hickey et al.

## **EXHIBIT A**

## On the production and use of the optical contact bond

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MS. received 20th April 1964

**Abstract.** The production and use of optical contact bonds including glass to glass and glass to fragile evaporated thin films is discussed. These bonds have freedom from chemical contamination and from uncertainty in mechanical location; they are permanent under normal conditions but may be dismantled for maintenance if necessary.

The technique of joining two surfaces by optical contact has been known for a long time but the potentialities of the bond do not appear to have been fully exploited. In this note we describe some unusual applications involving quite dissimilar materials, for example glass to soft surfaces such as calcite, single evaporated layers, and even dielectric multilayers.

The method used in achieving optical contact is essentially that given by Twyman (1957, p. 316). Of the alternatives discussed by him, viz. sliding one mating surface over the other or drawing a piece of tissue paper between the two surfaces, we prefer the latter where the surfaces are plane. Green's lens tissue (available from J. Barcham Green Ltd., Maidstone, England) is excellent for this purpose. For soft or fragile surfaces which cannot be rubbed we have found the use of such tissue paper essential in order to avoid damage to the surfaces.

Some examples of the use of optical contacting and its advantages are described.

Beam-splitters which are normally used in interferometry usually consist of an evaporated reflecting layer on a glass substrate. This system is unsymmetrical, the reflection coefficient being different for light incident on the two sides. Symmetry is achieved if the compensating plate is contacted to the beam-splitter. We have successfully used this technique with 60 mm diameter beam-splitters which have evaporated coats of ferric oxide or titanium dioxide as the semireflector.

It is possible to contact glass to multilayers, and this has been done in the construction of polarizing beam-splitters of the Banning (1947) type which usually consist of a prism whose hypotenuse face is coated with alternate dielectric layers, the refractive indices of the layers being chosen so that the rays are at the Brewster angles and the thicknesses such that the reflected beams are in phase. A second prism is then cemented to this multilayer stack. Optical contacting avoids troublesome interference fringes across the aperture which appear when cement is used. The reflections from the hypotenuse faces of the prisms are not at the Brewster angle and it should be possible to reduce the unwanted polarization component in the reflected beam by choosing the total thickness of the first and last evaporated layers to put these reflections out of phase. The use of cement does not offer this possibility. We have successfully contacted the hypotenuse face of a second prism on to a multilayer stack consisting of 16 alternate layers of zinc sulphide and cryolite deposited on the hypotenuse face of a prism with an aperture 15 mm square, using the tissue paper technique. Prior cleaning of the multilayer surface, especially if freshly evaporated, is not necessary and indeed should be avoided because of the possibility of damage.

For the production of thin parallel plates with thicknesses of the order of 1–2 mm and reasonably large areas, optical contacting to a master flat is necessary before the remaining side can be polished. This method has been applied in the production and assembly of a polarizing beam-splitter for a  $\frac{1}{2}$  Å birefringent filter (Steel, Smartt and Giovanelli 1961), the essential component of which is a plane-parallel piece of calcite, 2 mm thick, of rectangular cross section 100 mm × 43 mm. Fused silica windows 0.4 mm thick, 50 mm in diameter, parallel to better than  $\lambda/10$  have been produced in a similar way. Optical contacting has also been used to make small identical spacers for a tunable Fabry-Pérot interferometer (Ramsay and Kobler 1963), and for its assembly.

In the production of laser tubes, optical contact of the Brewster windows to the tube provides a gas-tight seal which introduces negligible distortion in the window and which does not introduce contamination into the system. This bond has the added advantage that it is demountable for cleaning purposes in the event of the windows becoming dirty during the assembly or lifetime of the laser tube.

Optical contacting (using the sliding technique) of spherical surfaces has been used in the production of compound lenses of interferometric quality; this avoids possible misalignment of the optical axes due to a cement wedge. It also has the advantage that there is no absorption, as is the case with cement. However, the mating surfaces must be finished to a higher degree of accuracy than is necessary if cement is used and care must be taken to avoid contact taking place before centring is achieved.

It is sometimes necessary to break optical contacts. If the two contacted surfaces have different thermal expansions, a heating of one will usually break the bond. If this fails, soaking for protracted periods in a low viscosity solvent should be tried. Failing this, forcing the bond apart by means of a razor blade will separate the surfaces. Occasionally, however, separation of components, particularly if they are of the same material, may result in the pulling out of a piece from one component which remains bonded to the other.

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## **EXHIBIT B**



US005724185A

# United States Patent [19]

Hickey et al.

[11] Patent Number: 5,724,185  
[45] Date of Patent: Mar. 3, 1998

## [54] METHOD FOR OPTICALLY CONTACTING SURFACES STRESSED BY AN OPTICAL COATING

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[73] Assignee: Hughes Danbury Optical Systems, Inc., Danbury, Conn.

[21] Appl. No.: 516,342

[22] Filed: Aug. 17, 1995

[51] Int. Cl.<sup>5</sup> ..... G02B 1/10; B32B 31/00; B05D 5/06

[52] U.S. Cl. .... 359/500; 359/582; 359/900; 156/99; 156/102; 156/153; 65/43; 65/61; 427/162

[58] Field of Search ..... 359/900, 580, 359/582, 496, 500; 156/99, 102, 151, 153, 160; 65/42, 43, 61

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Primary Examiner—Paul M. Dzierzynski

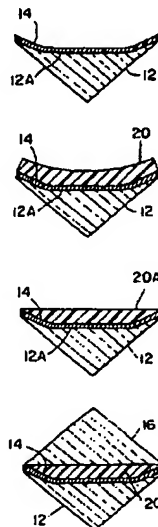
Assistant Examiner—John Juba, Jr.

Attorney, Agent, or Firm—W. C. Schubert; W. K. Denson-Low

## [57] ABSTRACT

In the method and apparatus of the present invention, a first optical element having a surface stressed by an optical coating is optically contacted with a second optical element. The first optical element is treated with a frequency or polarization selective coating which causes deformation of the treated surface. A pliable intermediate optical element is joined with the coated surface. The intermediate element is sufficiently pliable to substantially conform to the contour of the coated surface, providing optical contact therebetween. An opposite face of the intermediate element is polished and a second optical element is optically contacted to the intermediate element. This provides a precise and economical method for joining two optical elements, one of which is treated with an optical coating.

14 Claims, 2 Drawing Sheets





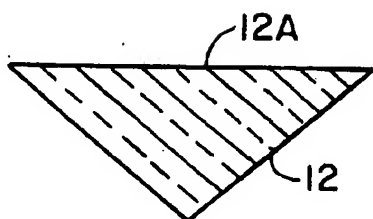


FIG. 1A  
PRIOR ART

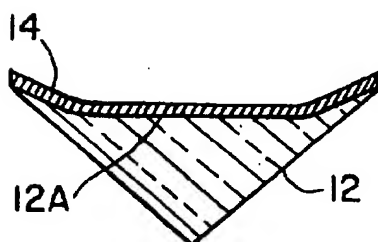


FIG. 1B  
PRIOR ART

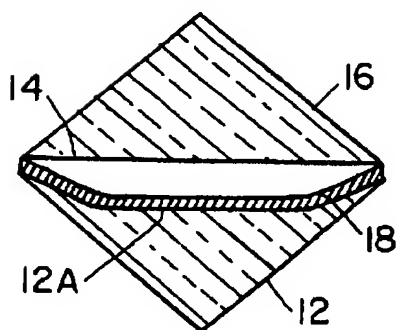


FIG. 1C  
PRIOR ART

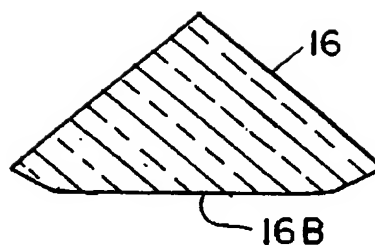


FIG. 2A

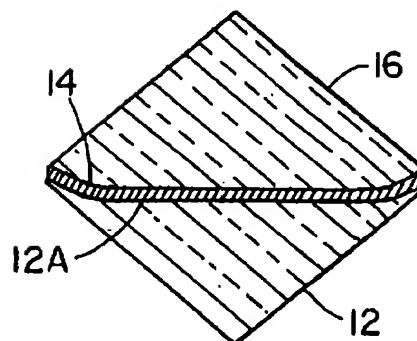


FIG. 2B

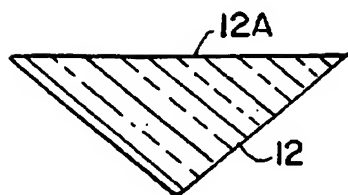


FIG. 3A

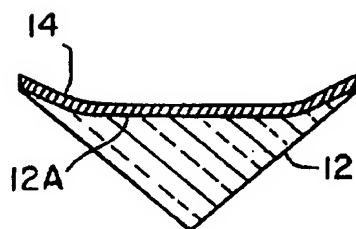


FIG. 3B

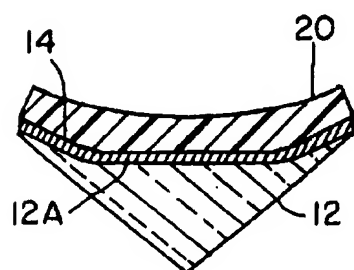


FIG. 3C

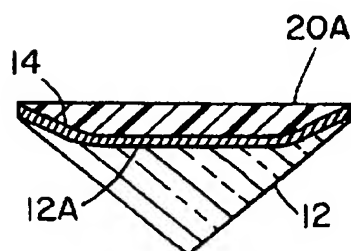


FIG. 3D

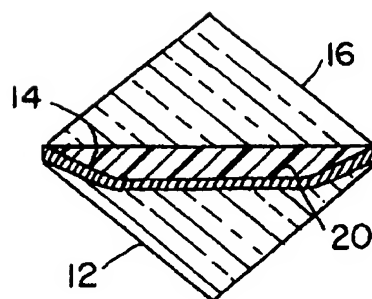


FIG. 3E

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# METHOD FOR OPTICALLY CONTACTING SURFACES STRESSED BY AN OPTICAL COATING

## BACKGROUND OF THE INVENTION

Optical components such as beam splitters and filters can be formed by adhering two optical elements together with a frequency or polarization selective coating layer therebetween. Adhering the two parts is often necessary to achieve the desired optical performance or to protect the coating from the environment. The indices of refraction of the incident and emergent optical media on each side of the coating are important parameters in achieving efficient operation. If a foreign substance, such as air, is present between the coating and either optical medium, then the optical performance of the device is compromised. Optical contacting is a well-known and preferred method for joining the elements, because it provides strong contact forces, without introducing the absorption and scatter of conventional adhesives.

Stresses inherent in the coating can cause the treated surface to become distorted or warped. Surface distortion interferes with optical contacting. To overcome this problem, the optical element to be mounted on the coated element can be ground or otherwise distorted to match the distortion of the coated element, thereby providing well-matched mating surfaces for optical contact. However, this can be a complicated and expensive procedure, as the distortion of the coated element is both difficult to predict and difficult to match to a mating surface. This method for optical contacting does not lend itself well to a manufacturing process which requires low cost, high yield, and/or predictability in forming the optical elements.

Optical contacting is a process which is well known to those skilled in the field of optics. There are varied theories for the mechanism of optical contacting. In one theory, the surfaces are held together by the surface tension of a very thin layer of water (or other liquid) located between the two surfaces. In another theory, mechanical seizure between the two surfaces occurs because two surfaces in close proximity tend to share a weak contact force (which has been described as the result of sharing electrons, or of sharing electromagnetic fields, or of Van der Waals forces, or of London dispersive forces). When the region of contact has sufficient surface area, a strong contact force is obtained by the cumulative effect of this weak interaction. It has been postulated that in practice, under conditions of greater than 50% relative humidity, a combination of both the surface tension and contact force theories apply. The region of contact between the surfaces must be substantially devoid of impurities, for example dust particles and water stains, to provide for the strongest bond. An absence, or near absence, of air is also necessary to eliminate or greatly reduce optical reflections at the contacted surfaces.

It is common in the art for various surfaces of optical elements to be treated with an optical coating which provides frequency or polarization selective properties. The coating can be reflective or transmissive of selected electromagnetic waves. For example, beam splitter coatings, filter coatings, antireflection coatings, reflective coatings, and multi-spectral coatings can be deposited on the optical element to produce any desired effect, for example, beam splitting or filtering. In many of these coatings, the absence of air is necessary to achieve the desired filter properties of the coating.

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It is also well known in the art that upon deposition, the optical coating contains inherent stresses which deform the treated surface of the optical element. This is especially true for prisms where it is common for the perimeter of the treated surface to be much thinner than the center of the treated surface. This causes the edges to be much more susceptible to deformation.

## SUMMARY OF THE INVENTION

The present invention is directed to a method and apparatus provided for optically contacting a first optical element coated with a frequency or polarization selective coating to a second optical element in a manner which overcomes the above-described limitations. The method of the invention comprises first depositing a frequency or polarization selective coating on a surface of a first optical element. Next, a pliable second optical element having first and second faces is mounted on the coated surface of the first element. The contour of the first face of the second element substantially conforms to the contour of the coated surface of the first element to provide optical contact therebetween.

In a preferred embodiment, the second face of the second element is polished to a predetermined profile and a third optical element having a mating surface to that of the second face of the second element is mounted thereon. The mating surface of the third element substantially conforms to the profile of the second element thereby providing optical contact therebetween. The profile is preferably flat. The second element is preferably formed with a high aspect ratio, for example, greater than five, providing requisite flexibility for conforming to the deformed surface of the coated optical element.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIGS. 1A-1C illustrate a prior art process for bonding an optical mounting element to an optical base element having a frequency or polarization selective coating.

FIGS. 2A-2B illustrate a process in accordance with a first embodiment of the invention for achieving optical contact between an optical mounting element and a coated optical element.

FIGS. 3A-3E illustrate a process for optically contacting an optical mounting element to a coated base element with a pliable intermediate element in accordance with a preferred embodiment of the present invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is directed to a method and apparatus for optically contacting optical elements, one of which is treated with a frequency or polarization selective optical coating. The resulting structure comprises a base element and mounting element which are each optically contacted to an intermediate element. The base element is treated with an optical coating. The term "optical coating" as used herein includes coatings which are frequency and/or polarization selective. Stresses inherent in the optical coating cause the

treated surface of the base element to become distorted. In accordance with the invention, a pliable intermediate element is mounted on the treated face of the base element and conforms to the distorted surface, thereby providing optical contact to the base element. The intermediate element is then polished flat to mate with a flat surface of the mounting element, thereby providing optical contact therebetween.

FIG. 1A is an illustration of an optical element such as a prism 12 having a surface 12A to be treated with an optical coating. The coating 14 causes a deformation of the element 12, as shown in exaggerated form in FIG. 1B. The actual resulting shape of the deformation depends upon the inherent material properties of the base element 12 whose surface 12A is treated, the stresses inherent in the coating 14, and the degree to which the coating 14 adheres to the treated surface 12A. As shown in FIG. 1C, if a mounting element 16 is mounted on the deformed base element 12, an air gap 18 remains therebetween. If the air gap 18 is large enough, optical contact may not be possible. Optical contact can only be achieved in this manner if the coating stress is low enough to introduce negligible deformation in the coated element. Otherwise, undesirable adhesives will have to be used.

To overcome this problem, the contacting surface 16B of the mounting element 16 can be formed to match the distorted profile 12A of the treated base element 12 as shown in FIGS. 2A and 2B. In this manner, the mounting element 16 will optically contact the base element 12, without a remanent air gap 18 therebetween. This is an expensive approach, however, since the shape is probably aspherical and since it is difficult to predict the distortion of the base surface 12A due to unrepeatable and unknown inherent stresses in the coating 14. These stresses can vary between production lots, causing the distortion to vary a significant amount. Furthermore, even if the degree of distortion 12A were predictable, it would be difficult and expensive to grind and polish a mating distorted surface 16B on the mounting element 16.

The preferred embodiment of the present invention overcomes the limitations described above. A base optical element 12 is formed with a contacting surface 12A having a predetermined profile, preferably flat as shown in FIG. 3A. In FIG. 3B, the surface 12A is treated with an optical coating 14 by any of the various well known coating deposition techniques. Inherent stress in the deposited coating causes a distortion in the optical surface 12A of the base element 12.

As shown in FIG. 3C, a pliable intermediate optical element 20 is mounted on the coated surface 12A of the base element 12. The intermediate element 20 is flexible and formed with a high aspect ratio.

Aspect ratio is defined as the ratio of the longest surface length to the thickness of the piece. It determines, along with the material properties, the degree to which an element is capable of distorting. The greater the distortion 12A of the base element 12, the higher the desired aspect ratio of the intermediate element 20. The preferred aspect ratio is such that the element must be thicker than the sag due to distortion caused by the coating, and at the same time must be pliable enough to conform to the distorted surface.

As an example, a circular element with a 1 inch diameter and a thickness of 0.04 inches has an aspect ratio of 25. An intermediate element with an aspect ratio of 25 would achieve optical contact with a base element having 5.0 micrometers of sag distortion.

The optical coating 14 is preferably thin, for example 0.5 micrometers; is relatively smooth, for example less than 100

Angstroms rms roughness; and is of sufficient mechanical integrity to withstand the process of optical contacting. The coating 14 performance is determined in part by the indices of refraction of the optical media in contact therewith. Because the intermediate element 20 conforms to the distorted surface 12A of the base element 12, substantially minimal impurities such as air remain in the junction therebetween. In this way, the coating 14 operates in a predictable manner as the indices of refraction of the incident medium 12 and emergent medium 20 are known and predictable, and the effect of impurities, for example air, in the junction are minimized.

In FIG. 3D, the surface 20A of the intermediate element 20 opposite that which is contacted to the deformed surface 12A, is prepared for optical contact with a mounting element 16 as shown in FIG. 3E. The simplest and most straightforward method for providing optical contact between the intermediate element 20 and mounting element 16 is to polish the contacting surfaces 20A flat. In FIG. 3E, a flat surface of the mounting element 16 is brought into optical contact with the intermediate element 20.

In this manner, a base element 12 treated with an optical coating is brought into optical contact with a mounting element 16, by virtue of a pliable intermediate element 20.

The base element 12, intermediate element 20, and mounting element 16 may comprise similar or different materials. Preferred materials include: glass; semiconductors; infrared materials, for example zinc sulfide or zinc selenide; crystalline materials for example sapphire and calcium fluoride; and polymers used in optics. Preferred substances for forming mirrors include Pyrex™, ULE™, and Zerodur™.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

We claim:

1. A method for optically contacting an optically coated optical element comprising the steps of:

forming an optical coating on a surface of a first optical element, said coating causing said surface to deform; and

joining a second optical element having first and second faces with said coated surface of said first optical element; said second element being sufficiently pliable such that said first face of said second element substantially conforms to said deformed coated surface to provide optical contact therebetween;

polishing said second face of said second optical element to a predetermined profile; and

joining a third optical element having a surface which substantially conforms to said predetermined profile of said second element with said second face of said second element to provide optical contact therebetween.

2. The method of claim 1, wherein the step of polishing further comprises polishing said second face of said second element substantially flat and wherein said third optical element has a substantially flat surface which joins with said second element to provide optical contact therebetween.

3. The method of claim 1, further comprising the step of determining the pliability of said second element by its aspect ratio.

4. The method of claim 3, wherein the aspect ratio is greater than 5.

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5. The method of claim 1, wherein the step of depositing an optical coating causes deformation in the first element due to inherent stresses in the coating.

6. The method of claim 1 wherein the optical coating is frequency selective.

7. The method of claim 1 wherein the optical coating is polarization selective.

8. A method for optically contacting an optically coated optical element to an uncoated element comprising the steps of:

forming an optical coating on a surface of a first optical element;

joining a second optical element having first and second faces with said coated surface; said second element being sufficiently pliable such that said first face of said second element substantially conforms to said coated surface of said first element to provide optical contact therebetween;

polishing said second face of said second element to a predetermined profile; and

joining a third optical element having a surface which substantially conforms to said predetermined profile of

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said second element with said second face of said second element, to provide optical contact therebetween.

9. The method of claim 8, wherein the step of polishing further comprises polishing said second face of said second element substantially flat and wherein said third element has a flat surface which joins with said second element to provide optical contact therebetween.

10. The method of claim 8, further comprising the step of determining the pliability of said second element by its aspect ratio.

11. The method of claim 10, wherein the aspect ratio is greater than 5.

12. The method of claim 8, wherein the step of depositing an optical coating causes deformation in the first element due to inherent stresses in the coating.

13. The method of claim 8 wherein the optical coating is frequency selective.

14. The method of claim 8 wherein the optical coating is polarization selective.

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